URBAN FIELD STUDIES FOR VERIFICATION AND VALIDATION OF ATMOSPHERIC DISPERSION MODELS

Martin J. Leach & Julie K. Lundquist
Lawrence Livermore National Laboratory

October 24, 2005

UCRL-PRES-215768

Work is performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Outline

- Requirements for dispersion verification and validation datasets
- URBAN 2000 – Salt Lake City, Utah, USA
- Joint URBAN 2003 – Oklahoma City, Oklahoma, USA
- Urban Dispersion Program – New York City, New York, USA
- Conclusions and recommendations for future datasets

Outline

- Requirements for dispersion verification and validation datasets
- URBAN 2000 – Salt Lake City, Utah, USA
- Joint URBAN 2003 – Oklahoma City, Oklahoma, USA
- Urban Dispersion Program – New York City, New York, USA
- Conclusions and recommendations for future datasets

Atmospheric dispersion models can be complex or simplistic, so datasets must be as complete as possible to provide rigorous tests for many models.

- Provide adequate meteorological description
  - For Gaussian models, perhaps one wind speed/wind direction observation is sufficient
  - For computational fluid dynamics models, an estimate of the relevant flow forcing (geostrophic wind) is optimal, but inlet profiles may suffice
- Sample the dispersion of tracer material
  - Ideal tracers do not disperse onto surfaces and are neutrally buoyant
  - Sampling frequently in space and time is optimal

Outline

- Requirements for dispersion verification and validation datasets
- **URBAN 2000 – Salt Lake City, Utah, USA**
- Joint URBAN 2003 – Oklahoma City, Oklahoma, USA
- Urban Dispersion Program – New York City, New York, USA
- Conclusions and recommendations for future datasets

Salt Lake City – Urban 2000 Experiment

Salt Lake City looking northwest

DOE CBNP funding
Nighttime, light winds, slightly stable conditions

Concurrent with the DOE Vertical Transport and Mixing (VTMX) meteorological experiment

Allwine, K.J. et al., 2002, "Overview of URBAN 2000: A Multiscale Field Study of Dispersion through an Urban Environment," *Bulletin of the American Meteorological Society*, **83**, pp. 521-536.

Dense meteorological network provided surface and profile wind measurements, which were vital in this region of complex topography

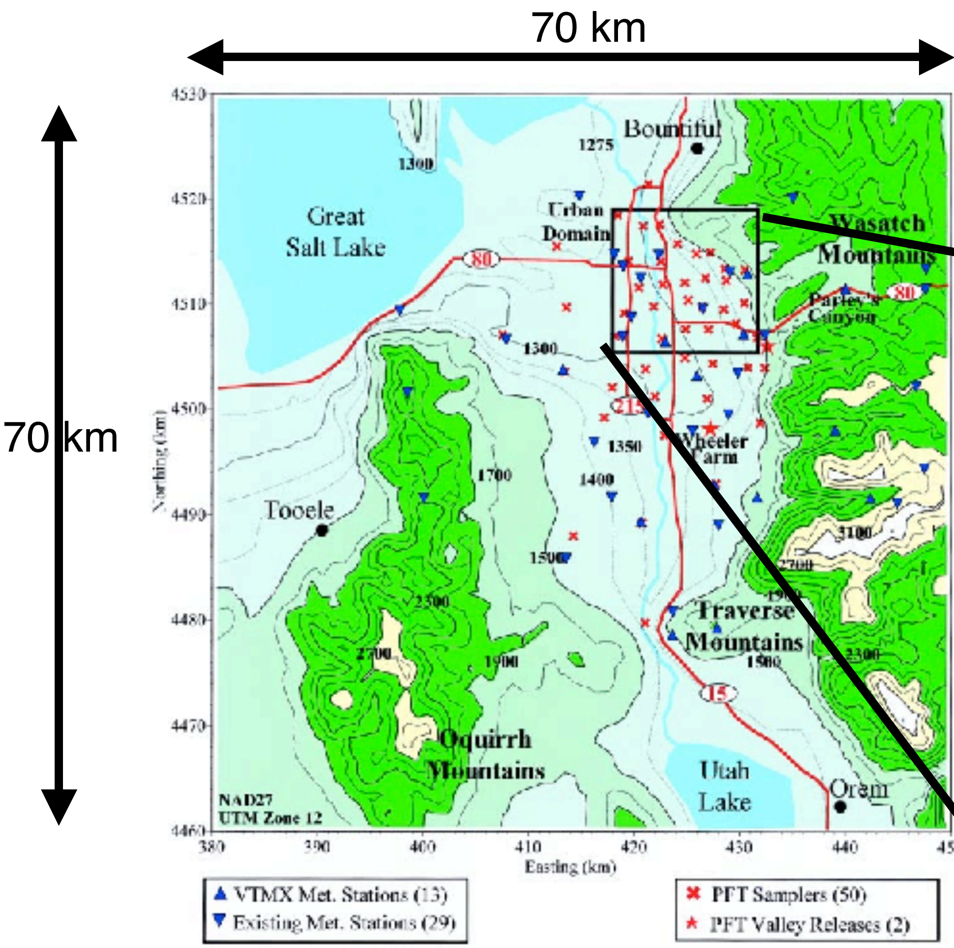
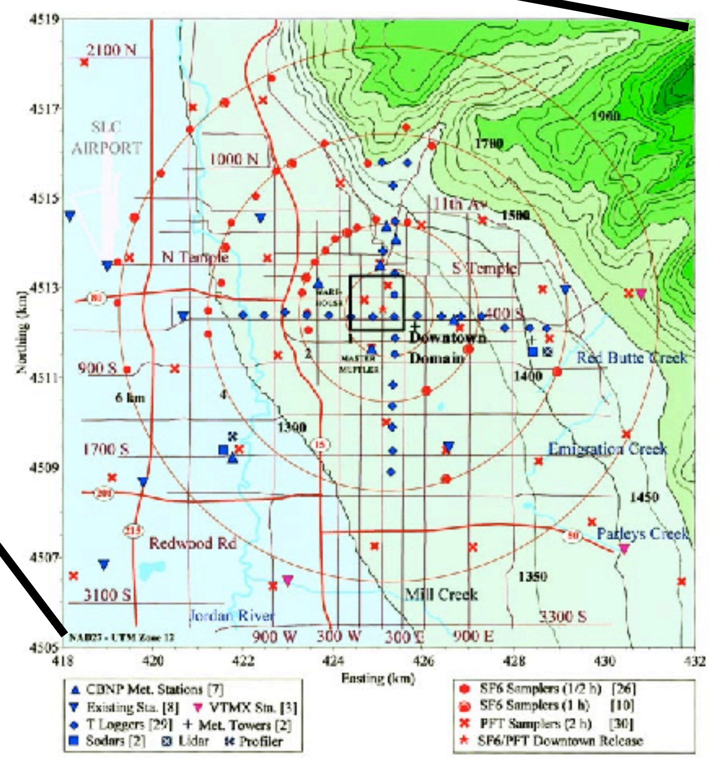


FIG. 2. Map of Salt Lake Valley (*regional domain*) showing terrain elevations (m) and locations of VTMX tracer samplers, surface meteorological stations, and valley release locations.

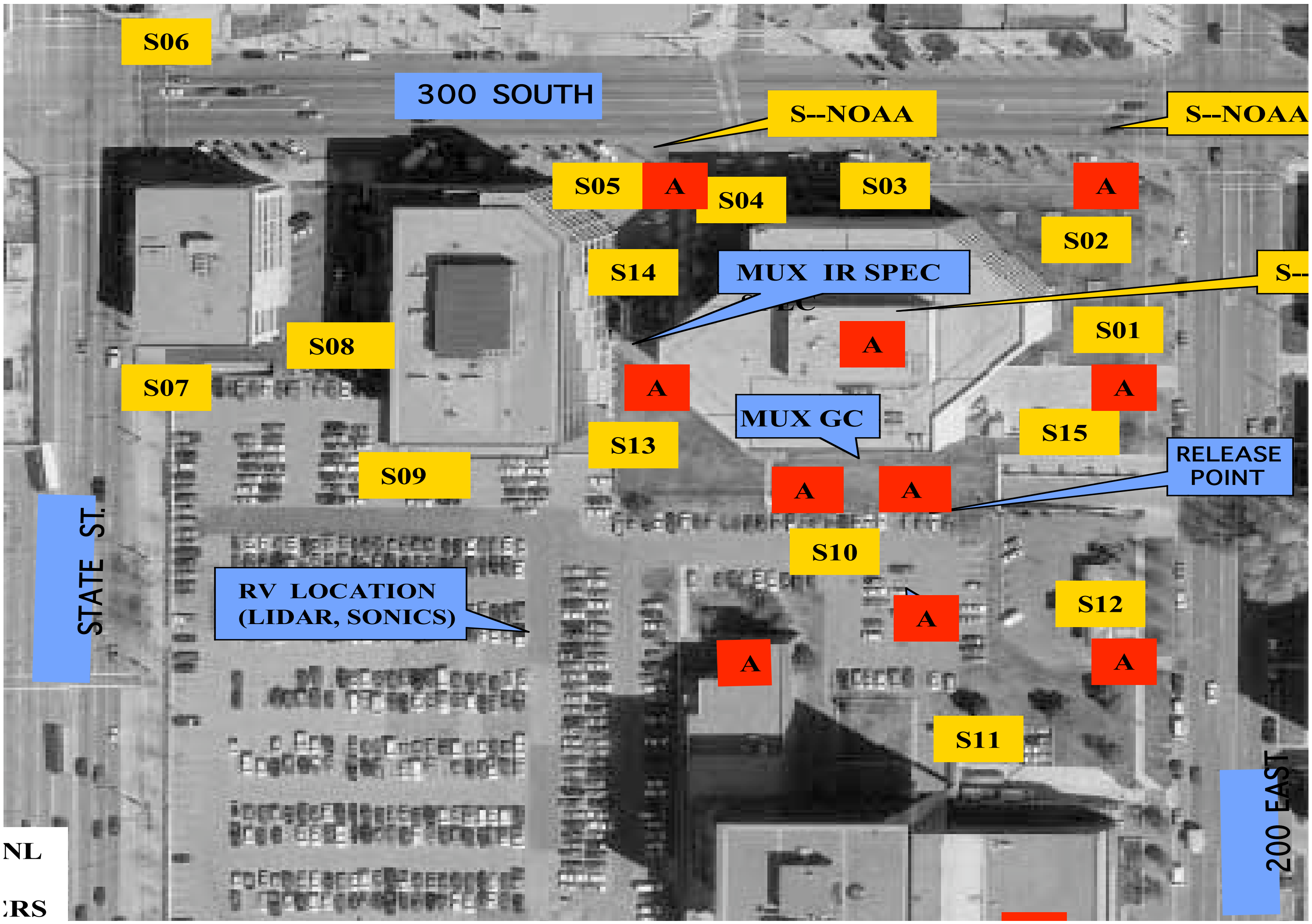
The concurrent VTMX meteorology experiment provided extensive surface meteorological stations in the regional domain



Air samples collected at surface and on building rooftops

Downtown SLC showing the four elevated tracer sampler locations (red arrows) and two downtown tracer release locations (blue arrows). The top picture is looking to the northwest and the bottom picture is looking to the southeast. (Photographs from Don Green Photography, Salt Lake City, Utah.)

Near sources, several sonic anemometers and air samplers were deployed



2D or 3D sonic anemometers

Gas samplers

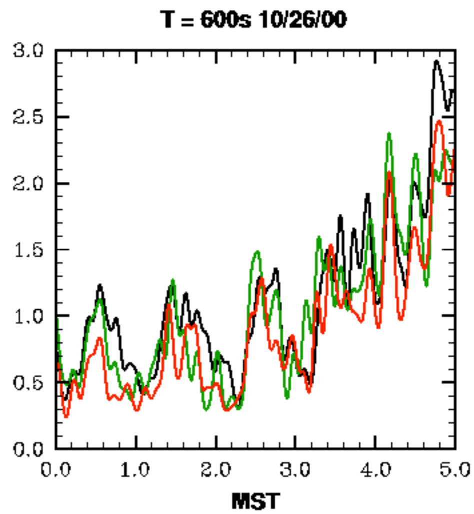
Six nighttime releases of SF6 and PFT tracers are available for testing dispersion models

TABLE 3. Overview of six SF_6 and six PFT tracer experiments.

IOP no.	Start[a] Date (DOY)[c]	Start[a] MST	Stop[b] Date (DOY)	Stop[b] MST	Tracers[d]	Meteorology
2	6 Oct 2000 (280)	2200	7 Oct 2000 (281)	1200	SF_6 line; PFTs	Strong easterly downslope winds after 0000–0300 MST penetrating 1–2 km into valley at the surface
4	8 Oct 2000 (282)	2200	9 Oct 2000 (283)	1200	SF_6 line; PFTs	Clear skies, weak winds, well-developed drainage; approaching trough eroded inversions after 0500 MST
5	14 Oct 2000 (288)	2200	15 Oct 2000 (289)	1200	SF_6 line; PFTs	Clear skies, weak winds, well-developed drainage
7	17 Oct 2000 (291)	2200	18 Oct 2000 (292)	1200	SF_6 line; PFTs	Clear skies, weak winds, well-developed drainage; approaching trough eroded inversions after 0500 MST
8	19 Oct 2000 (293)	2200	20 Oct 2000 (294)	1200	PFTs only	Clear skies, weak winds, well-developed drainage
9	20 Oct 2000 (294)	2100	21 Oct 2000 (295)	0900	SF_6 point only	Cloudy skies, weak to moderate winds, weak drainages; affected by approaching troughs
10	25 Oct 2000 (299)	2200	26 Oct 2000 (300)	1200	SF_6 point; PFTs	Cloudy skies, moderate winds, weak drainages; affected by approaching troughs

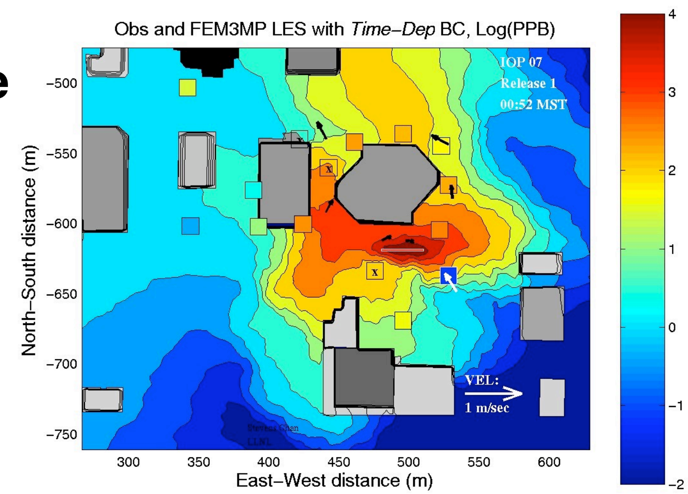
[a] Start of tracer sampling.
[b] End of tracer sampling.
[c] Day of year.
[d] SF_6 point and line releases, PFT point releases only.

URBAN 2000 results: Ultimately, the local dispersion is a result of scale interaction

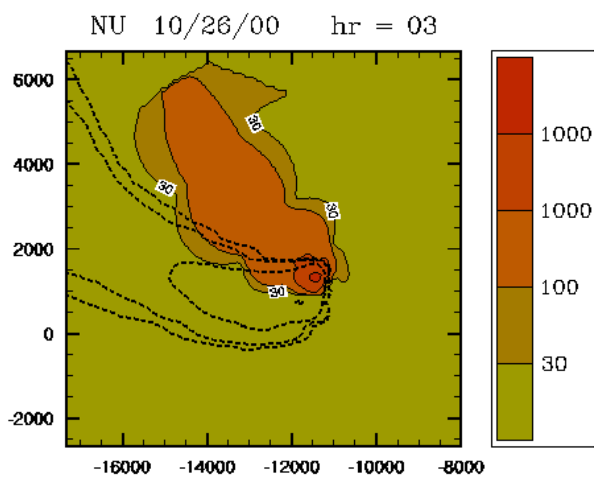


Upwind sensor with a 10-minute filter

Time dependent BC in FEM3MP

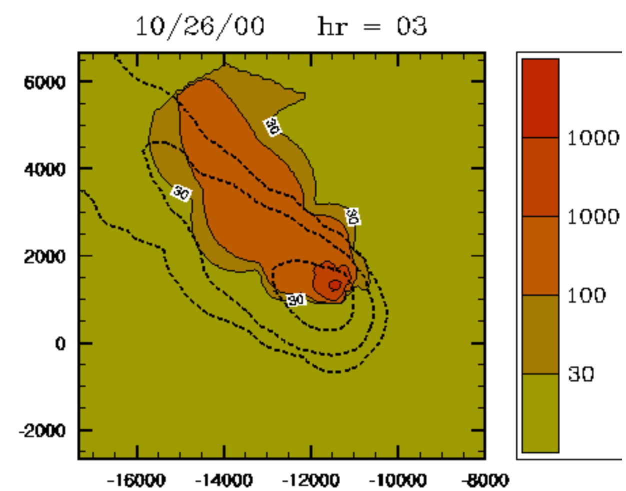


Mesoscale dispersion forecast



without urban effects

with urban effects



Several types of air samplers provided measurements of concentrations of SF6

- **Within 300m of source, infrared spectrometers with ~ 1 Hz time resolution were deployed**

- **Within 1 km of source, integrated bag samplers (collecting air for subsequent analysis in a laboratory) were deployed. These instruments typically collected data in 10-minute intervals**

- **Distributed along arcs 1 km, 2 km, and 4 km from the source were other bag samplers, collecting data at 30-minute intervals**

Outline

- Requirements for dispersion verification and validation datasets
- URBAN 2000 – Salt Lake City, Utah, USA
- **Joint URBAN 2003 – Oklahoma City, Oklahoma, USA**
- Urban Dispersion Program – New York City, New York, USA
- Conclusions and recommendations for future datasets

Joint URBAN 2003 was the largest urban dispersion experiment ever conducted

Oklahoma City, Oklahoma

- Conduct field studies to scientifically, statistically and operationally evaluate urban dispersion models…indoor and outdoor
- Analyze field data to identify and describe the governing physical processes for scientifically evaluating models
- Provide quality assured data sets and documentation to the science community

Funding from the Dept. of Energy CBNP program, the Department of Homeland Security, the Department of Defense Threat Reduction Agency, the Army Research Office

Participation by LLNL, LANL, PNNL, LBNL, NOAA, the Army Research Lab, the Department of Transportation, DSTL, ITT, the University of Utah, Oklahoma University, Indiana University, Arizona State U

The ultimate goal is to predict dispersion in, through and around urban areas

Work is performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

Documentation of urban meteorology was a high priority for Joint URBAN 2003

ARL Lidar

DPG Sodar

DPG FM-CW Radar

- **3 boundary-layer wind profilers (40km upwind, 5 km upwind, 5 km downwind from city center)**
- **2 sodars (5 km upwind, 5 km downwind)**
- **3 locations for radiosonde launches**
- **2 towers for profiles of turbulence quantities**
  - **10 km upwind (4 levels)**
  - **1 km downwind (8 levels)**
- **2 Doppler lidars**
- **1 FM-CW radar**

Several high rate turbulence instruments were deployed within 1 km of the tracer sources

- These instruments can provide data for testing high-resolution CFD models
- These instruments can also provide input for simpler dispersion models
- The turbulence measurements also provide information on the structure of atmospheric turbulence in the urban environment

For more information:

Contacts at LLNL:

Marty Leach: leach6@llnl.gov
Julie Lundquist: lundquist1@llnl.gov

Some preliminary results from OKC

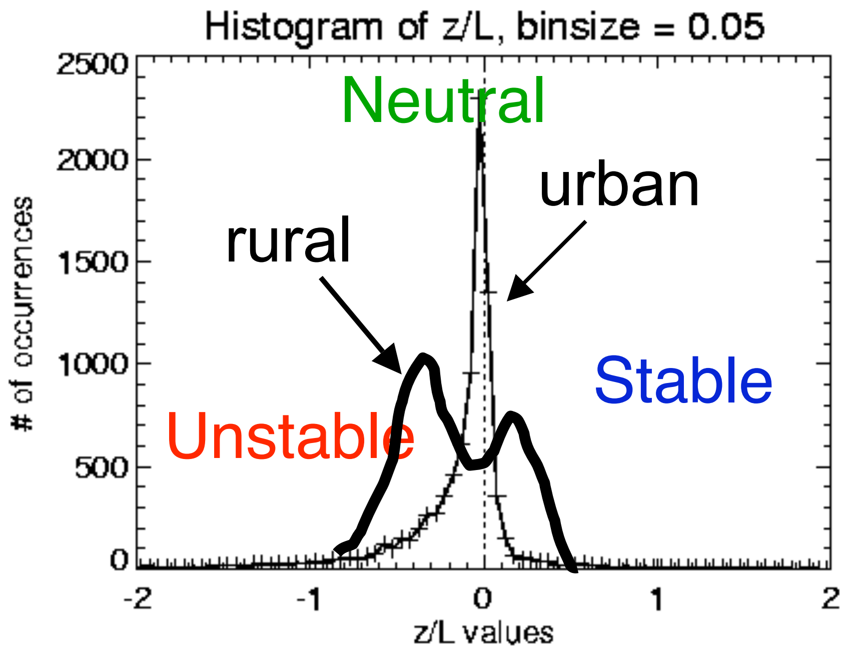
- Profiles of high frequency wind observations using sonic anemometers seem to indicate an imbalance in the turbulence budget
- Comparison of rooftop tracer samplers to those on the ground seem to indicate an effect from thermal circulations

We deployed a unique instrument platform to profile the urban atmosphere

A construction crane was used to construct a platform for obtaining vertical profiles of wind and tracer in the urban area.

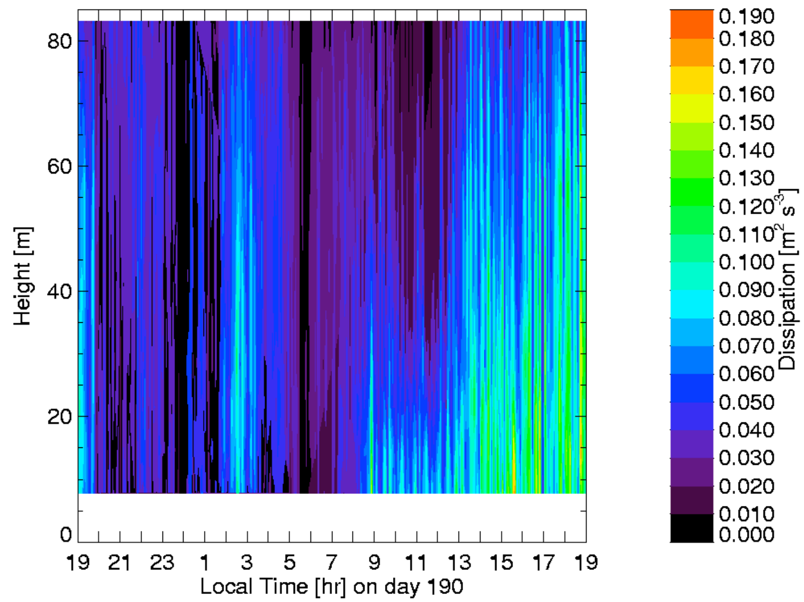
The tracer samplers were deployed to collect data to evaluate different scale models

Stability and turbulence characteristics differ in the urban boundary layer



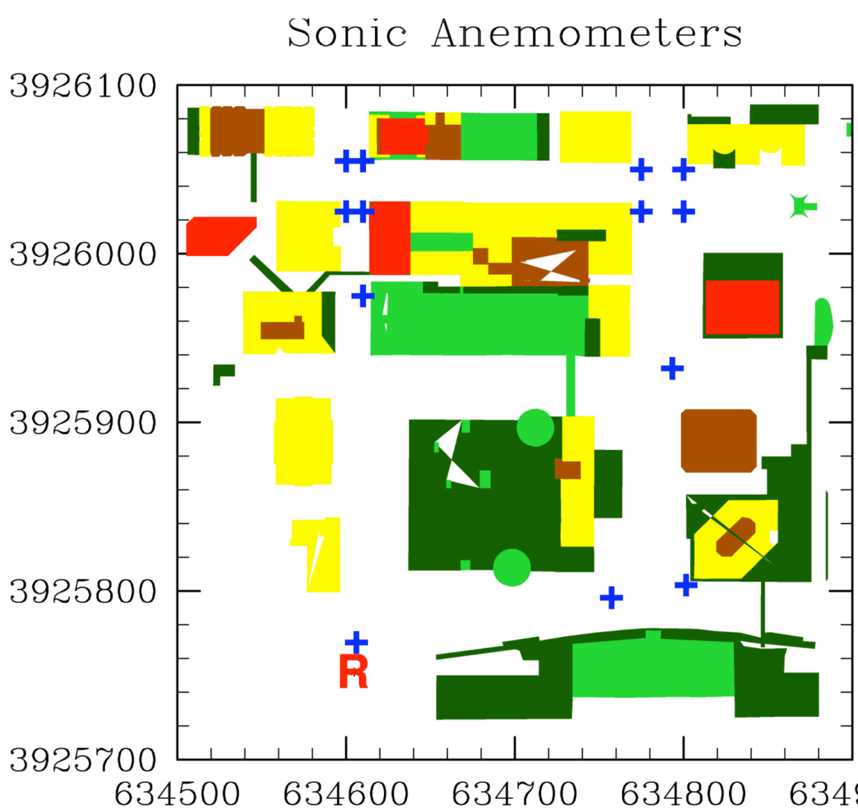
An urban atmosphere tends to more neutral stability than a rural atmosphere

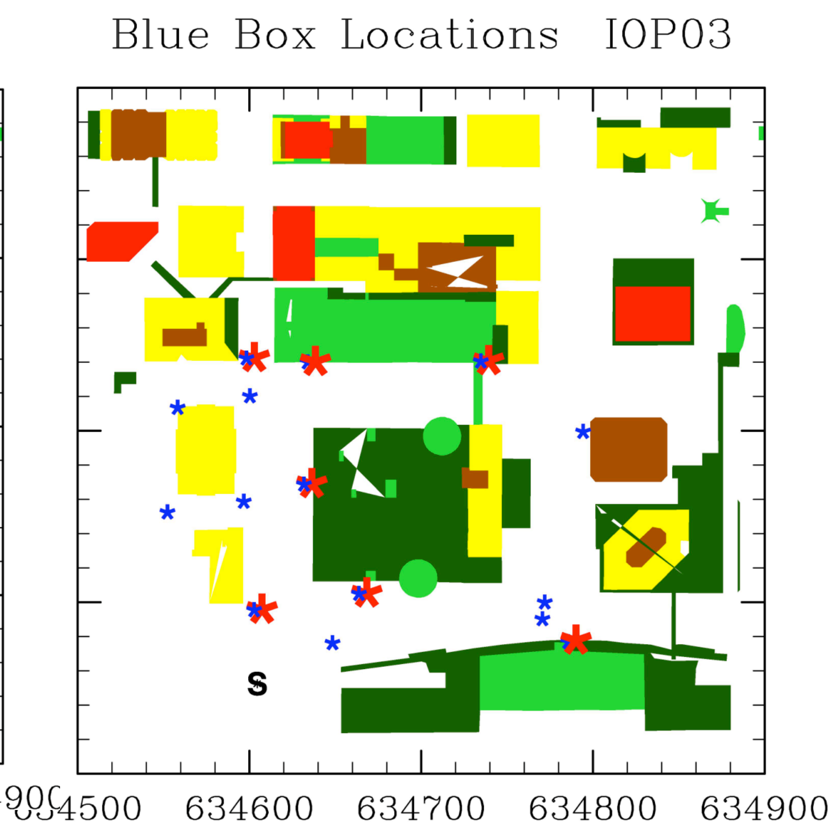
The presence of turbulence dissipation indicates the lack of balance that is assumed in turbulence parameterization schemes used in numerical models.



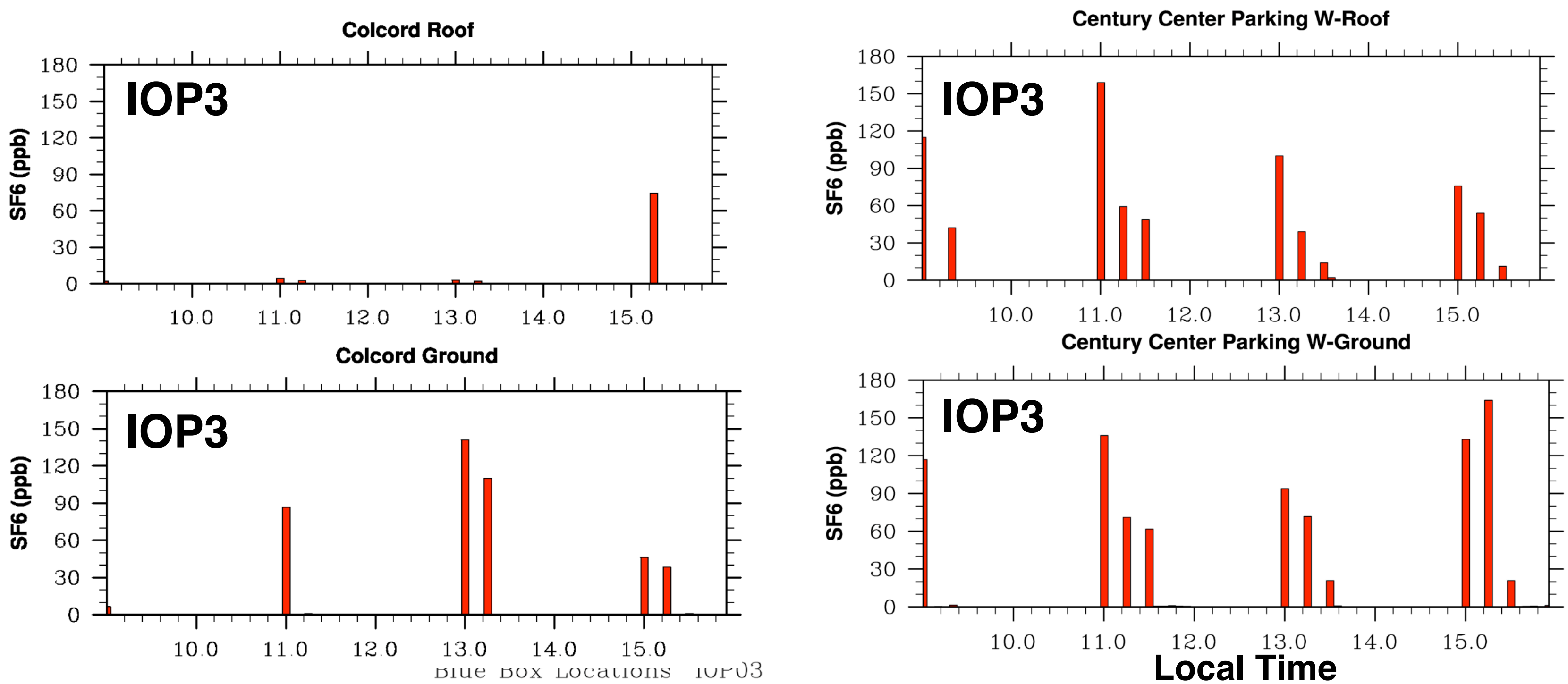
Results courtesy of Julie Lundquist

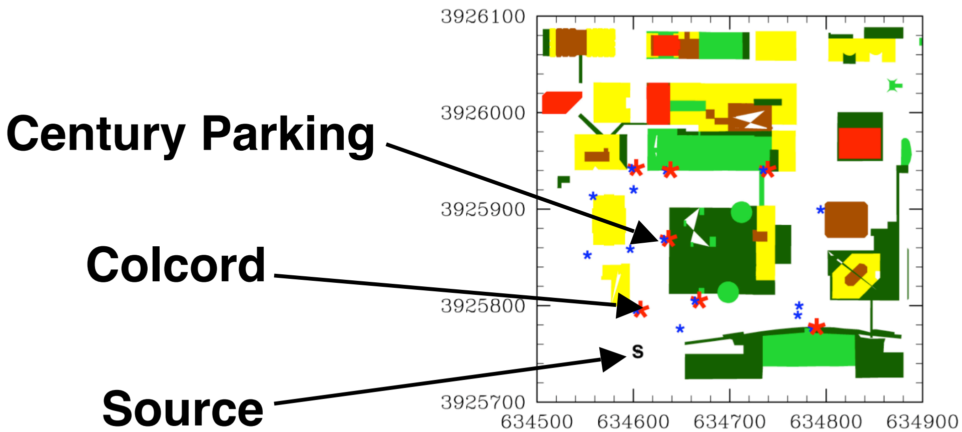
The experimental layout in the near-field





Vertical Mixing: What role does thermal forcing play in dispersion?



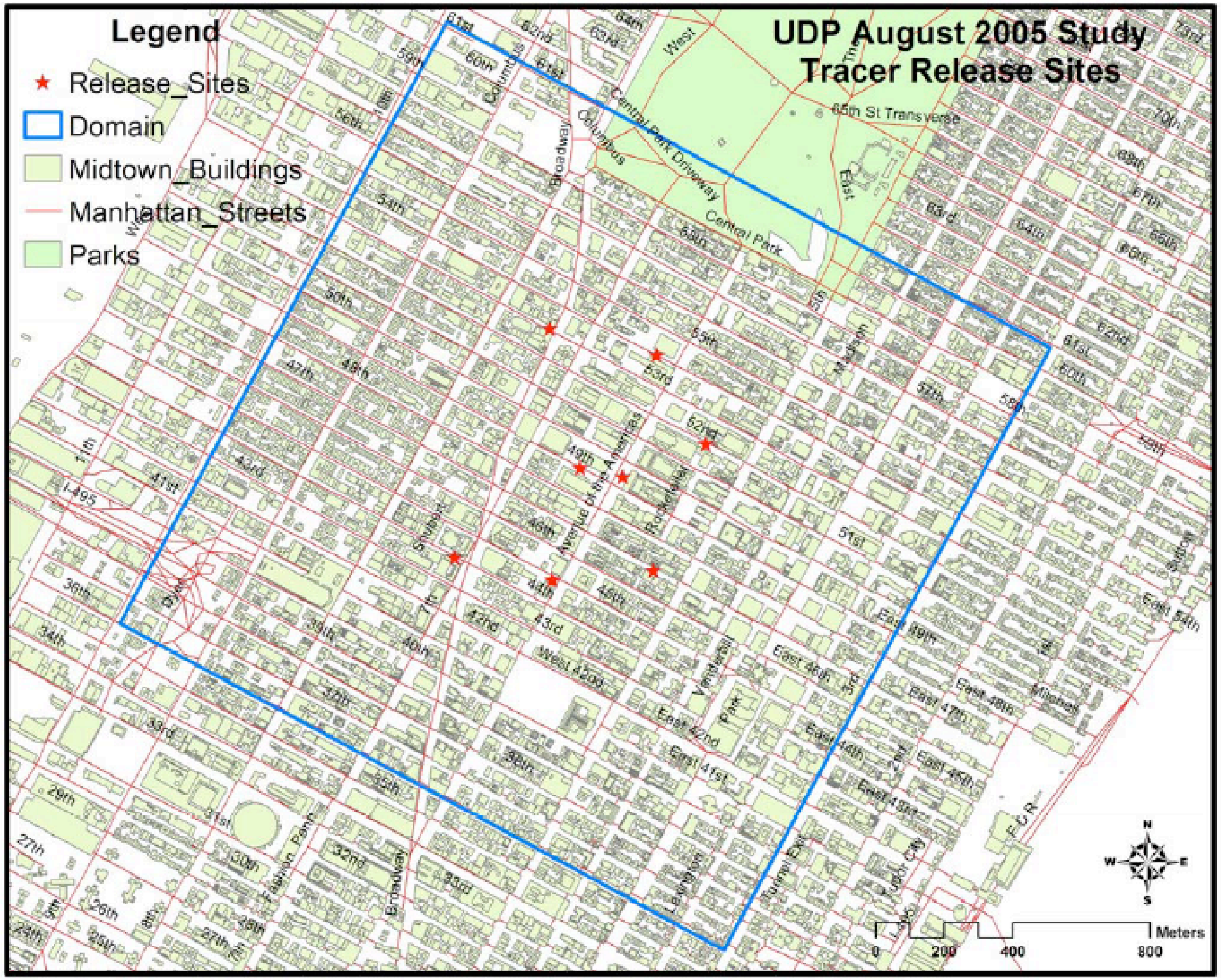


Rooftop concentrations often equal or exceed those at street level, suggesting thermal forcing plays a role.

Outline

- Requirements for dispersion verification and validation datasets
- URBAN 2000 – Salt Lake City, Utah, USA
- Joint URBAN 2003 – Oklahoma City, Oklahoma, USA
- **Urban Dispersion Program – New York City, New York, USA**
- Conclusions and recommendations for future datasets

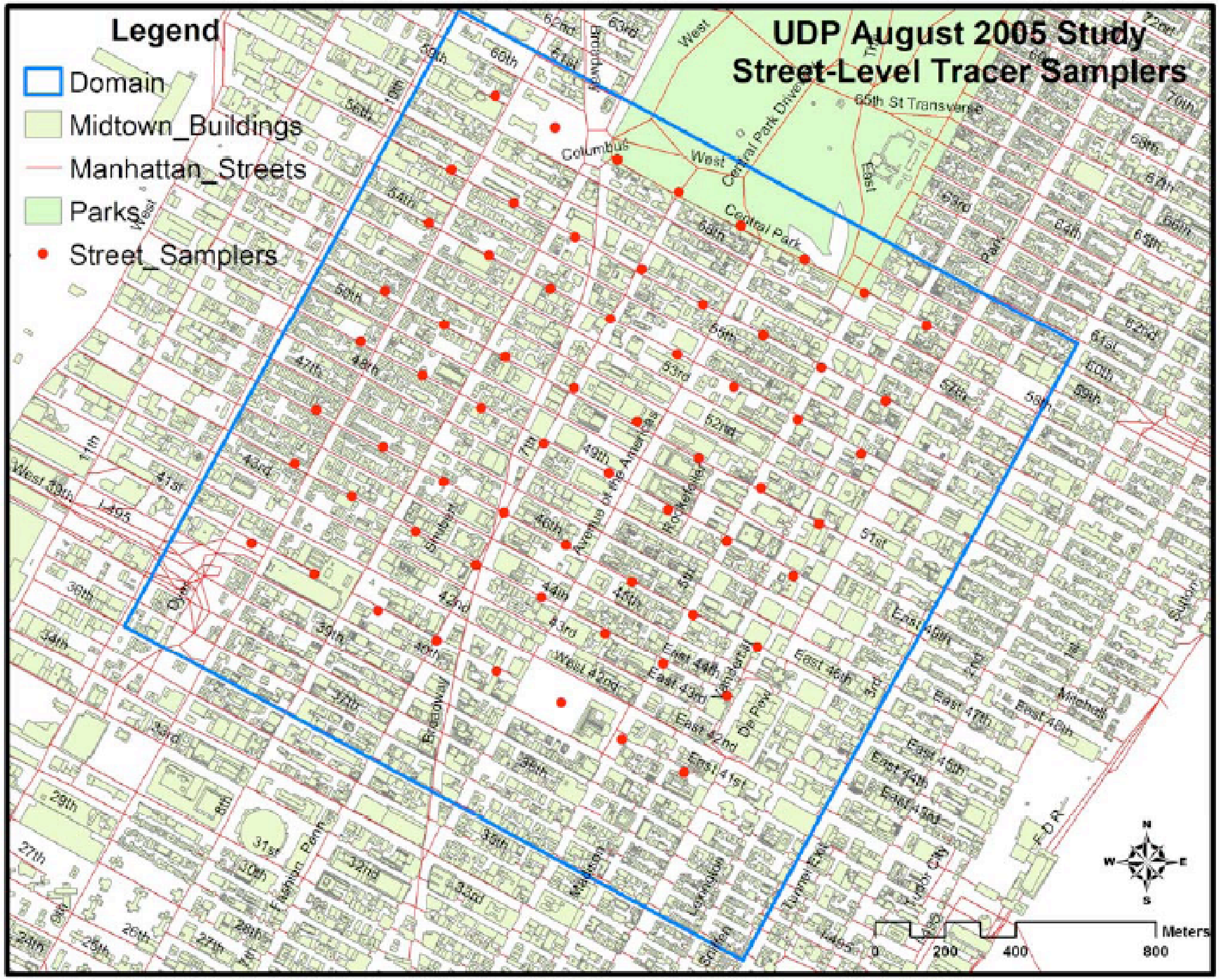
Urban Dispersion Program: New York City, Aug 2005



Tracers (SF6 and PFT) were released at various points in the domain

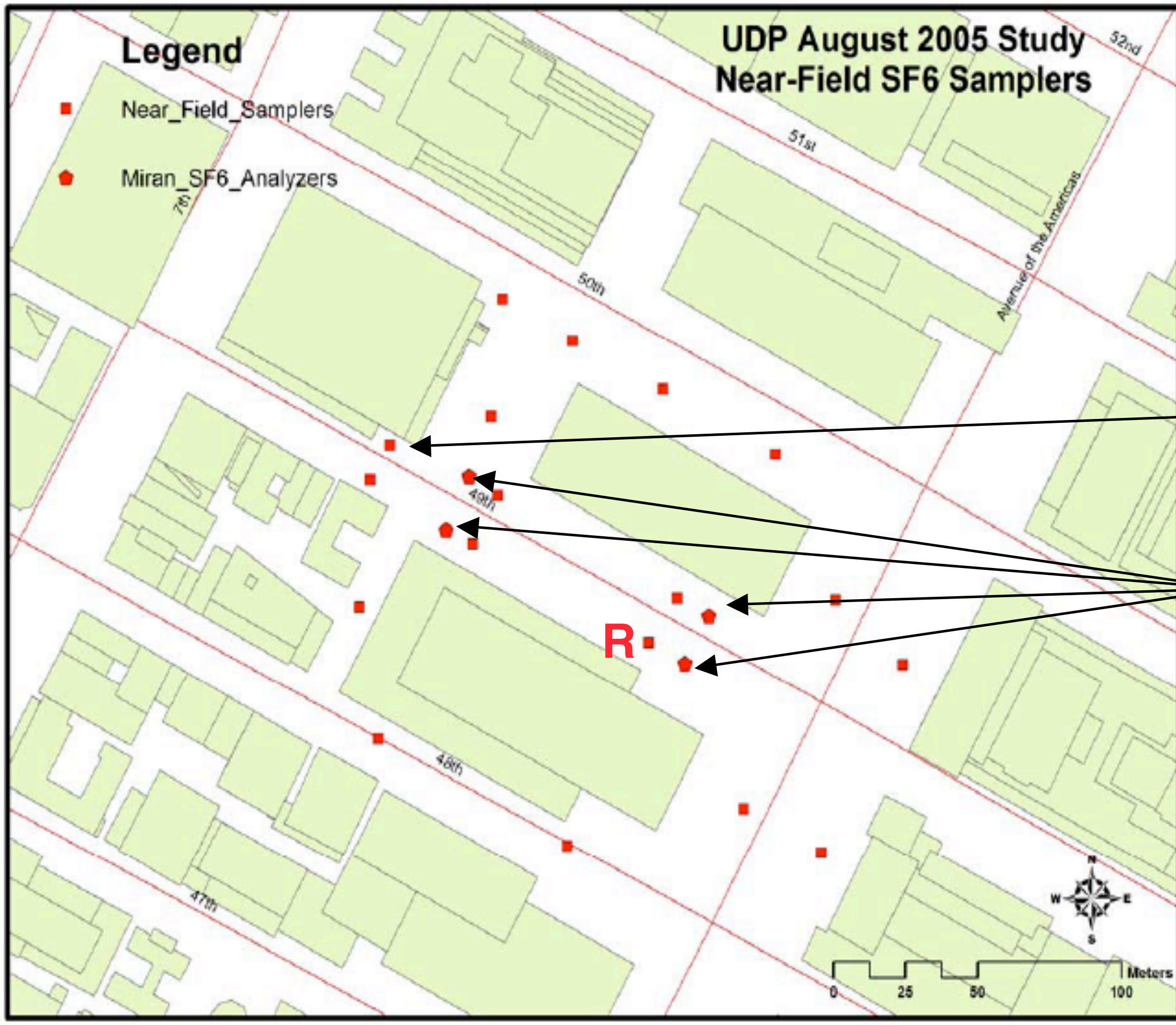
The experiment domain is a 2km x 2km box in Midtown Manhattan

Samplers were deployed in a grid around the release points



These integrated samplers were analyzed for both SF6 andPFT, using ECD in a Gas Cromatograph

Near field samples were analyzed for SF6 only.



Near field samplers included a profile along a tall building and real-time analyzers at street level.

R is the release point

A meteorological network was established

ROOFTOP STATION

msg04_met_instruments
041012 mr

SETBACK STATION

SODAR

The network was intended to characterize the urban atmosphere from street level, in the urban canyons and above rooftops

The network included street level met stations

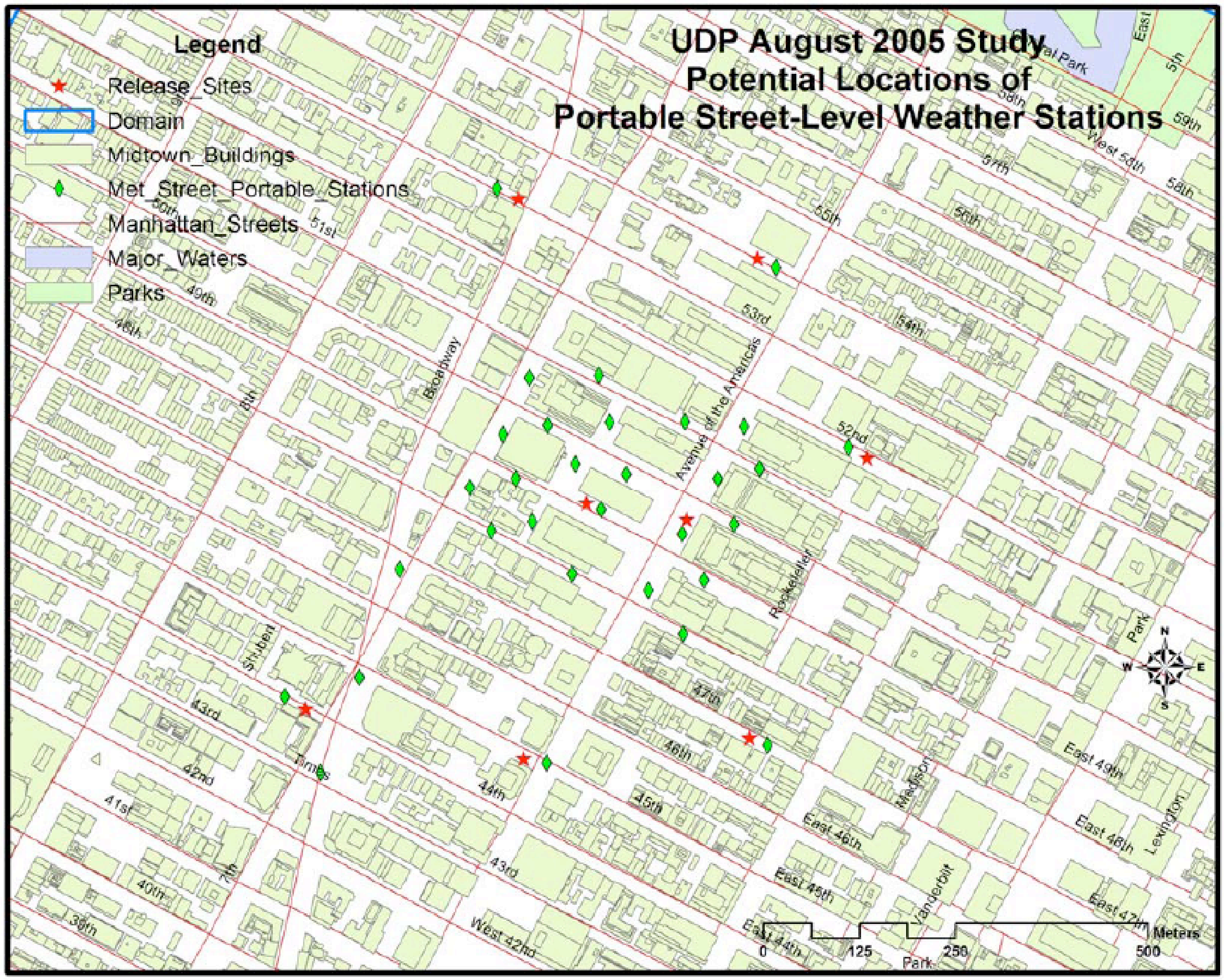


Figure 13. Shown are the 31 possible locations for the fifteen portable weather stations to be deployed at street-level during each IOP. Also shown are the possible release locations (star symbols).

Temperature sensors were deployed to observe the Urban Heat Island

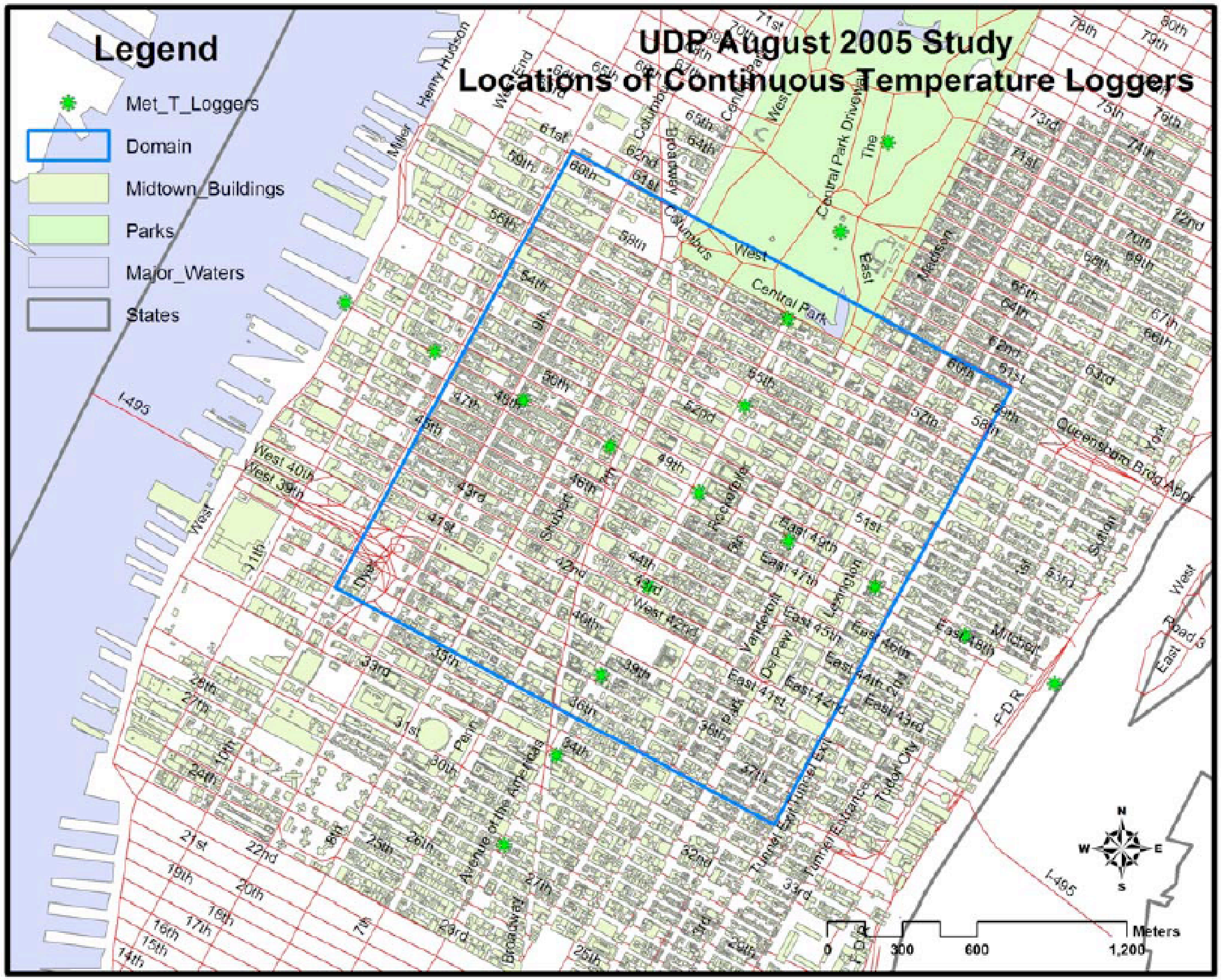


Figure 14. Shown are the 17 locations for the portable temperature loggers to be deployed on light poles across the Midtown Manhattan study area.

The sensors crossed the experiment domain in two directions

Outline

- Requirements for dispersion verification and validation datasets
- URBAN 2000 – Salt Lake City, Utah, USA
- Joint URBAN 2003 – Oklahoma City, Oklahoma, USA
- Urban Dispersion Program – New York City, New York, USA
- **Conclusions and recommendations for future datasets**

Summary and future recommendations

- Datasets exist from these experiments
- New ones need lots of meteorological instrumentation
- Physical processes in the urban atmosphere need to be better understood
  - What is the relative role of thermal/mechanical forcing?
  - What role does ambient stability play in the venting of material into the layer above the urban canopy?
  - What really is “anthropogenic” heating and how large is it?
  - How and how much do buildings create/destroy turbulence?
- New, better and faster tracer sampling techniques are desired.

The End

For more information contact:

Marty Leach: leach6@llnl.gov
Julie Lundquist: lundquist1@llnl.gov